

# RIKEN/BNL Research Center

<https://www.bnl.gov/riken/>

*Strong efforts in High Energy Nuclear Theory and Lattice Gauge Theory  
Experiment: Nuclear (PHENIX) & Cosmology*

RBRC Fellows: tenure track Assistant Professorships, joint with US Universities.

RBRC pays 2/3 of academic year salary for 5 years.

Fellows spend half time at RBRC, half at university

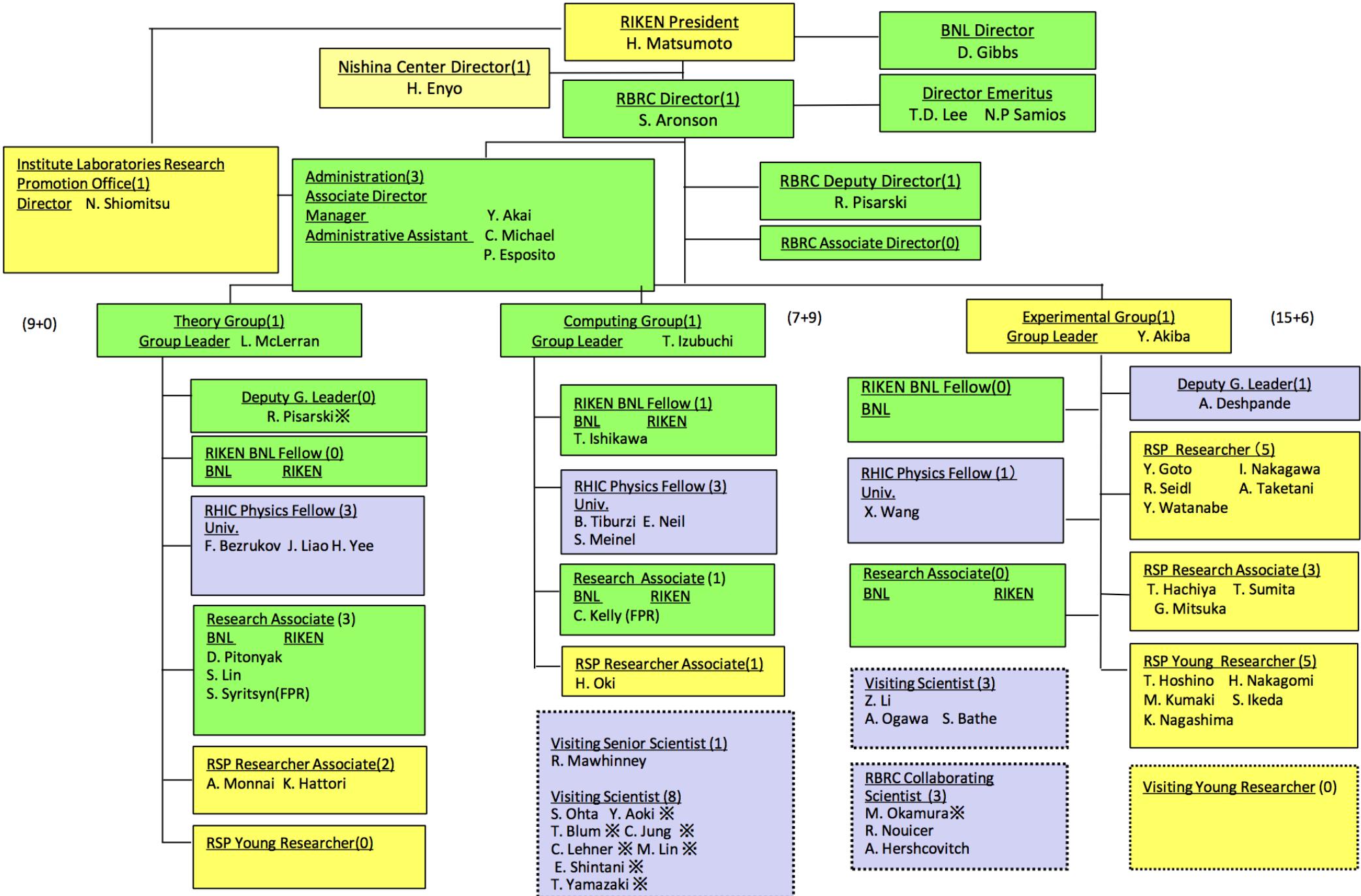
Postdocs: (mainly) funded through Japan and (a few) directly through RBRC  
Several small workshops per year. Yearly, ~ 100 papers, 50 invited talks

*Funded through 2018. Review in 2016 for renewal for 2018-2023.  
sPHENIX and eRHIC will figure prominently in renewal.*



# RIKEN BNL Research Center

As of July 1st, 2015



# RIKEN /BNL Administration

Directors Emeritus

*T. D. Lee*, 1997-2003

*N. P. Samios*, 2003-2013

Director

S. Aronson 2013 → present

Deputy Director

R. Pisarski

Theory Group Leader

L. McLerran → D. Kharzeev

Computing Group Leader

T. Izubuchi

Experimental Group Leader

Y. Akiba

Deputy Exp. Group Leader

A. Deshpande

# Groups: Theory, Computing, & Experiment

## Theory Group Members

**New: Dima Kharzeev**

L. McLerran, Group Leader

R. Pisarski, Deputy Group Leader

### Research

### Associates

[Koichi Hattori](#)

[Shu Lin](#)

[Akihiko Monnai](#)

[Daniel Pitonyak](#)

[Sergey Syritsyn](#)

### Fellows

[Fedor Bezrukov](#)

[Jinfeng Liao](#)

[Ho-Ung Yee](#)

## Computing Group Members

T. Izubuchi, Group Leader

### Research

### Associates

[Chris Kelly](#)

### Fellows

[Tomomi Ishikawa](#)

[Stefan Meinel](#)

[Ethan Neil](#)

[Brian Tiburzi](#)

## Experimental Group Members

Y. Akiba, Group Leader

A. Deshpande, Deputy Group Leader

### Research

### Associates

[Hidemitsu Asano](#)

[Yasuhiro Fuwa](#)

[Yuji Goto](#)

[Takashi Hachiya](#)

[Tomoya Hoshino](#)

[Shunsuke Ikeda](#)

[Masafumi Kumaki](#)

[Maki Kurosawa](#)

[Itaru Nakagawa](#)

[Hiroshi Nakagomi](#)

[Ralf Seidl](#)

[Atsushi Takedani](#)

[Yosuke Watanabe](#)

### Fellows

[Xiaorong Wang](#)

# Advisory Committees

## Theory:

Raju Venugopalan, BNL

Werner Vogelsang, Tübingen

Kenji Fukushima, Tokyo

Larry McLerran, BNL

## Lattice:

Kostas Orginos, William & Mary

Shoji Hashimoto, KEK, Tsukuba

Steve Sharpe, Seattle

Mike Creutz, BNL

## Experiment:

Akira Masaike, Aichi

Kenichi Imai, Kyoto

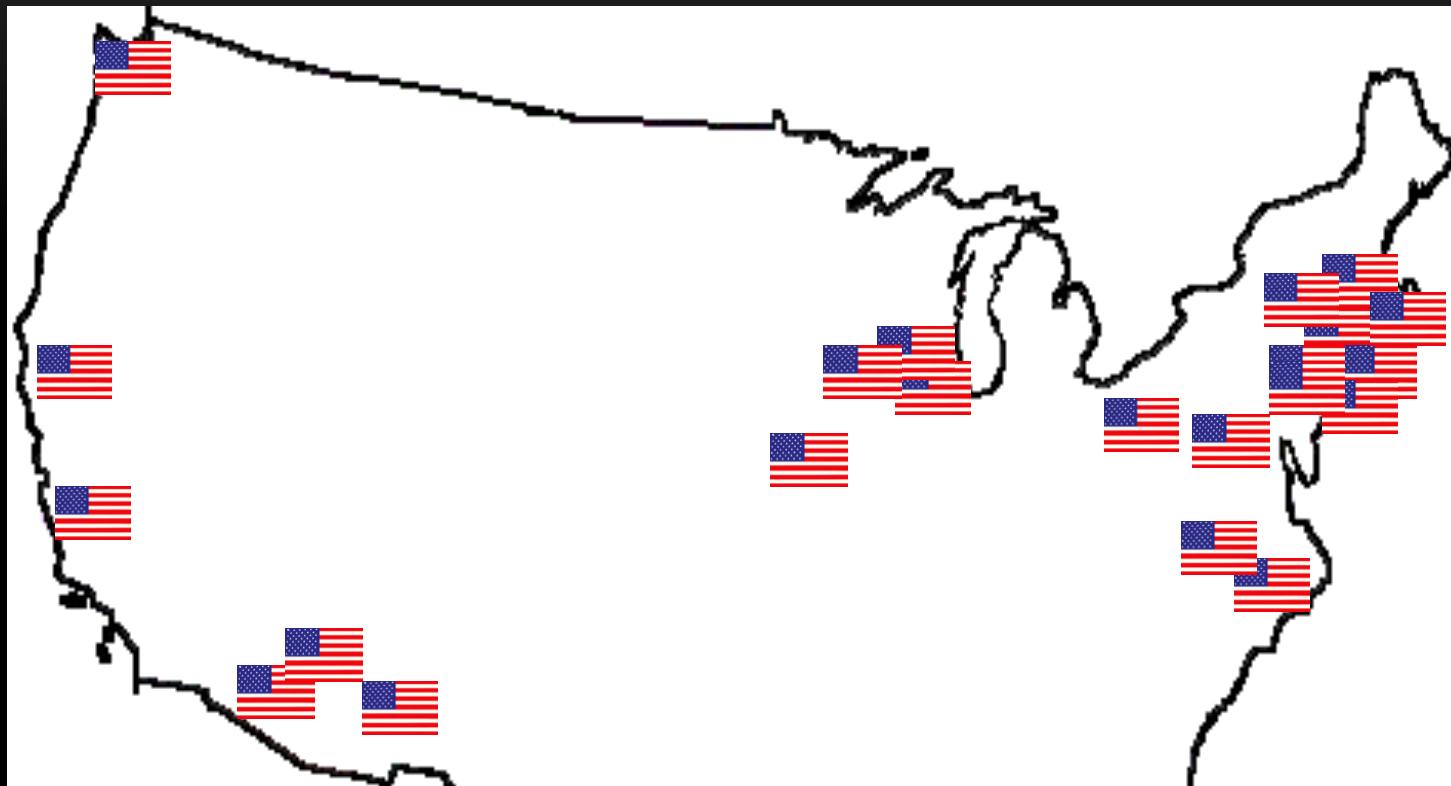
Yousef Makdisi, BNL

# Recent RIKEN /BNL Workshops

RBRC Workshops: *short* (2-3 days) *small* (20-30 people), on *specialized* topics.  
Since inception, 122 workshops.

- The Approach to Equilibrium in Strongly Interacting Matter,: April 2-4, 2014
- Thermal Photons and Dileptons in Heavy-Ion Collisions, Aug 20-22, 2014
- CreutzFest 2014: A Celebration of the Physics of Michael Creutz, Sept 3-5, 2014
- Multi-Hadron and Nonlocal Matrix Elements in Lattice QCD, Feb 5-6, 2015
- Theory and Modeling for the Beam Energy Scan: Feb 26-27, 2015
- Collectivity in Small Colliding Systems with High Multiplicity: March 4-6, 2015
- High  $p_T$  Physics in the RHIC-LHC Era: April 11-15, 2016

# Tenured RBRC Alumni In The U.S.



## Experimental Group

Bazilevsky, BNL  
Deshpande, Stony Brook U  
Fields, U New Mexico  
Grosse-Perdekamp, U Illinois  
Xie, Purdue  
Bathe, Baruch  
Kawall, U Mass Amherst

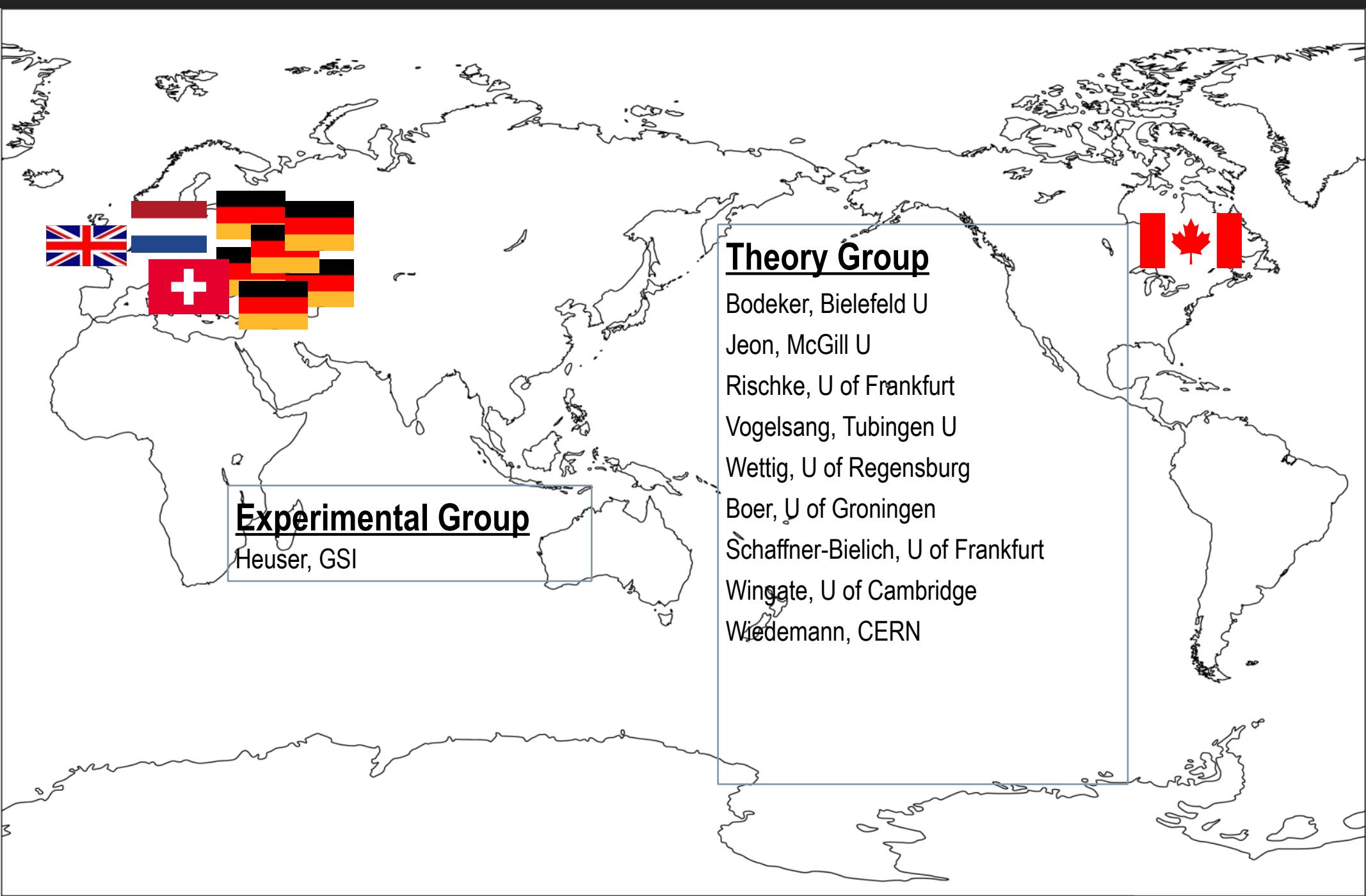
## Computing Group

Izubuchi, BNL

## Theory Group

Bass, Duke U  
Blum, U of Connecticut  
Dumitru, Baruch  
Fries, Texas A&M  
Kharzeev, BNL/SBU  
Kusenko, UCLA  
Lunardini, Arizona State  
Mocsy, Pratt  
Molnar, Purdue  
Orginos, William & Mary  
Petreczky, BNL  
Son, U of Chicago  
Schaefer, NCSU  
Stasto, Penn State  
Stephanov, U of Illinois  
Teaney, Stony Brook  
Tuchin, Iowa S U  
Van Kolck, Tuscon & Paris  
Venugopalan, BNL  
Yuan, Berkeley

# Tenured RBRC Alumni, Canada and Europe



# Tenured RBRC Alumni In Japan

## Theory Group

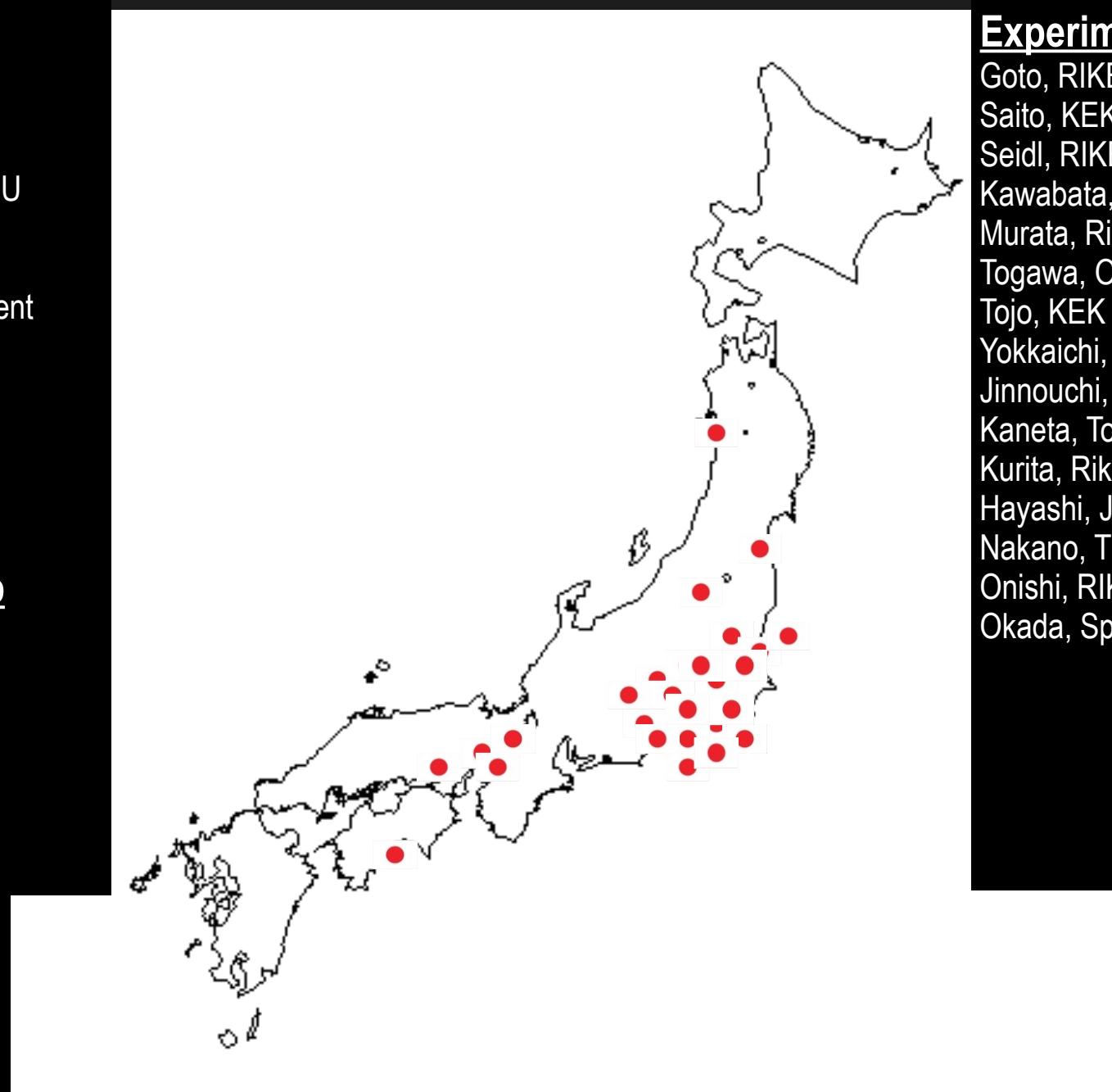
Iida, Kochi U  
Kitazawa, Osaka U  
Fujii, U of Tokyo  
Itakura, KEK  
Nemoto, St. Marianna U  
Sasaki, U of Tokyo  
Yamada, KEK  
Yasui, Tokyo Management  
Hirano, U of Tokyo  
Fukushima, Keio  
Doi, RIKEN  
Hidaka, RIKEN  
Nara, Akita Int. U

## Computing Group

Aoki, Nagoya  
Hatta, Kyoto U  
Hirono, Sophia U  
Fukushima, U of Tokyo  
Sasaki, Tohoku U

## Experimental Group

Goto, RIKEN  
Saito, KEK  
Seidl, RIKEN  
Kawabata, Kyoto U  
Murata, Rikkyo U  
Togawa, Osaka U  
Tojo, KEK  
Yokkaichi, RIKEN  
Jinnouchi, Titech  
Kaneta, Tohoku U  
Kurita, Rikkyo U  
Hayashi, JAEA  
Nakano, Titech  
Onishi, RIKEN  
Okada, Spring-8 (JASRI)



# RBRC Theory

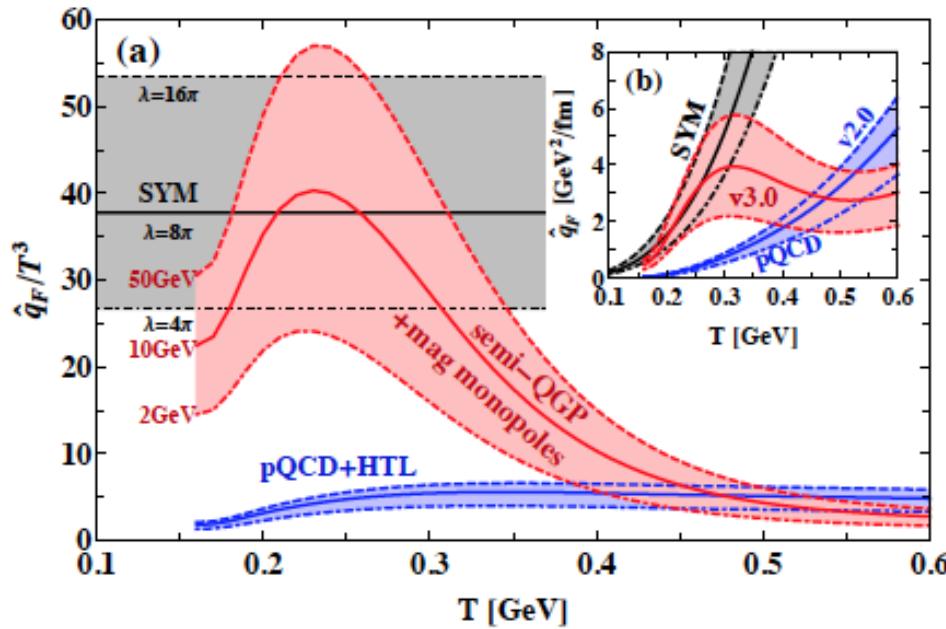
# J. Liao The Internal Working of sQGP

There are a number of outstanding challenges in understanding how the strongly coupled QGP does what it does:

- \* Nonperturbative dynamics and emergent degrees of freedom near confinement/deconfinement — how to implement such physics?
- \* Experimental & lattice data validation?
- \* Perfect fluidity v.s. Jet quenching — how to reconcile the two key properties?

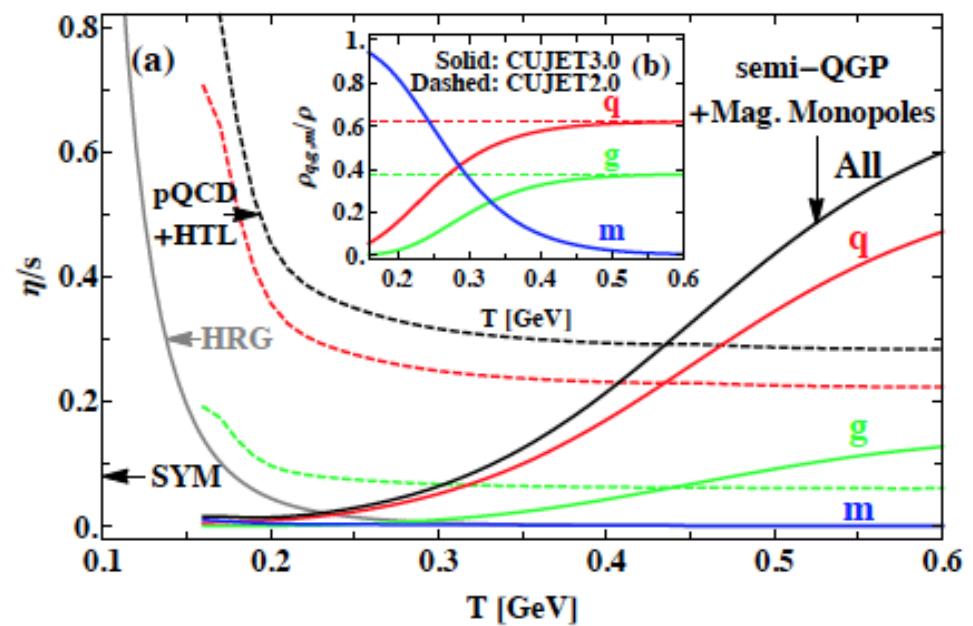
## Consistency of Perfect Fluidity and Jet Quenching in semi-Quark-Gluon Monopole Plasmas

Jiechen Xu,<sup>1,\*</sup> Jinfeng Liao,<sup>2,3,†</sup> and Miklos Gyulassy<sup>1,‡</sup>



Jet transport coefficient  $\hat{q}_F/T^3$  shows a strong peak near  $T_c$ !

CUJET3.0 framework implements essential near- $T_c$  physics:  
\* semi-QGP (Pisarski,...)  
\* emergent monopoles (Liao, Shuryak,...)  
\* data validated by RHIC+LHC



Shear viscosity,  $\eta/s$ , shows a clear minimum  $\sim 1/4\pi$  near  $T_c$ !

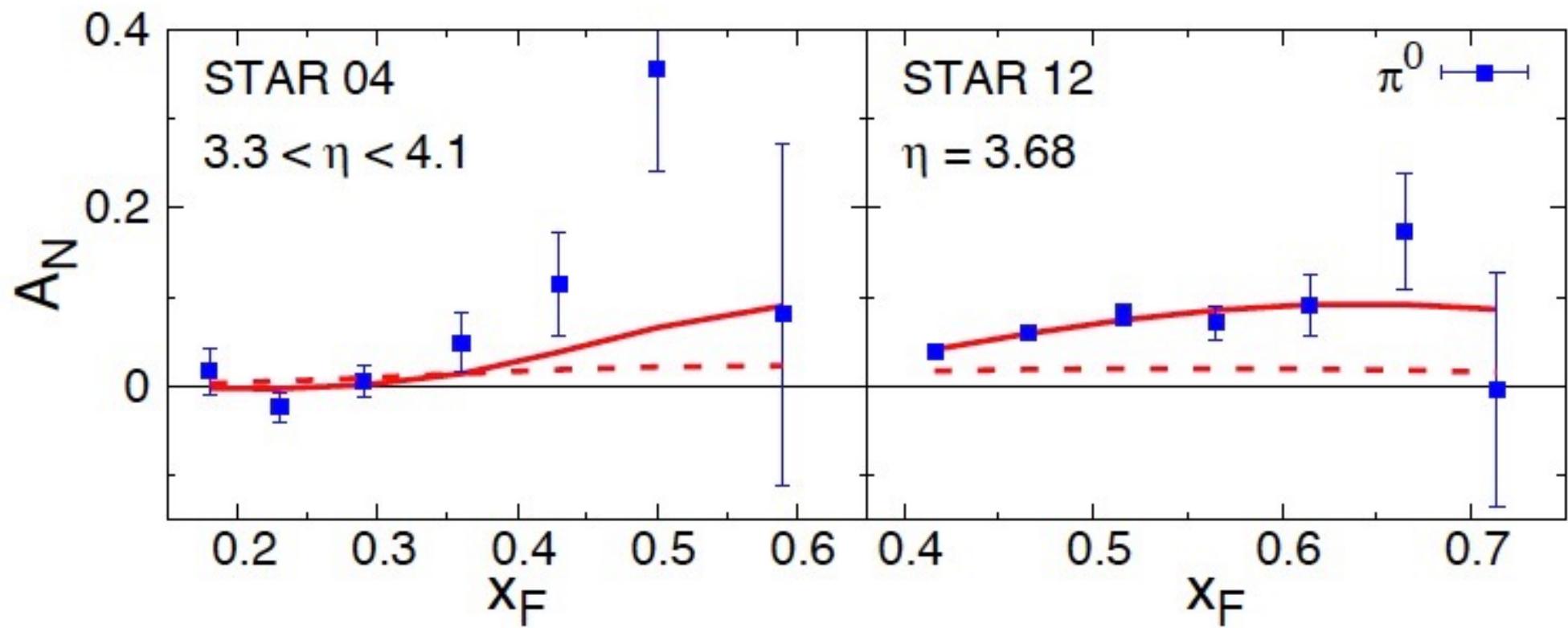
# D. Pitonyak

Transverse single-spin asymmetries for single hadrons,  $p^\uparrow p \rightarrow hX$

study twist-3 contributions, parton fragmentation, to amplitude  $A_N$

(Kanazawa, Koike, Metz, Pitonyak - PRD **89**(RC) (2014))

**Fragmentation + Qiu-Sterman** (soft gluon poles, Sivers function)



— Total, *including* twist 3 Fragmentation Functions

- - Without twist 3-parton Frag. Funcs.

$\chi^2/\text{d.o.f.} = 1.03$

**RBRC Lattice**

# Lattice calculations of hadron structure



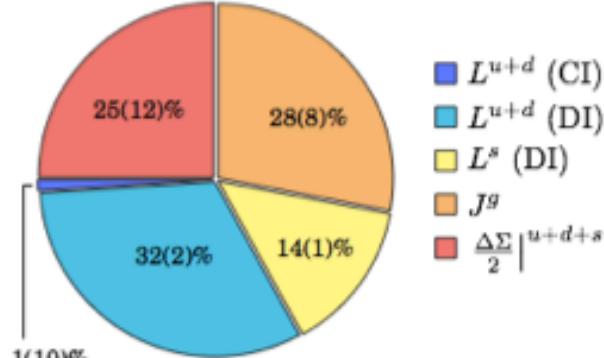
Lattice QCD

*RBRC team: develop QCDOC  
Supercomputers*

# Lattice calculations of hadron structure



Lattice QCD



Proton spin decomposition

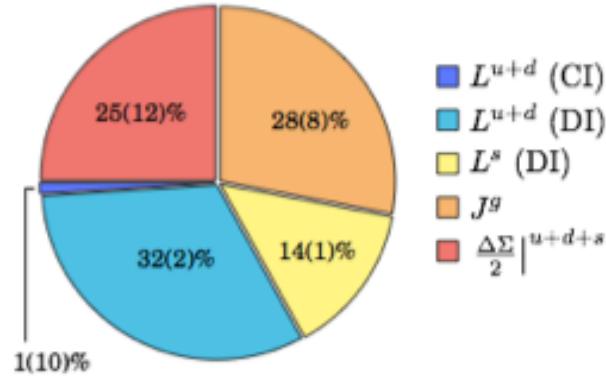
*RBRC team: develop QCDOC*

*Supercomputers*

# Lattice calculations of hadron structure

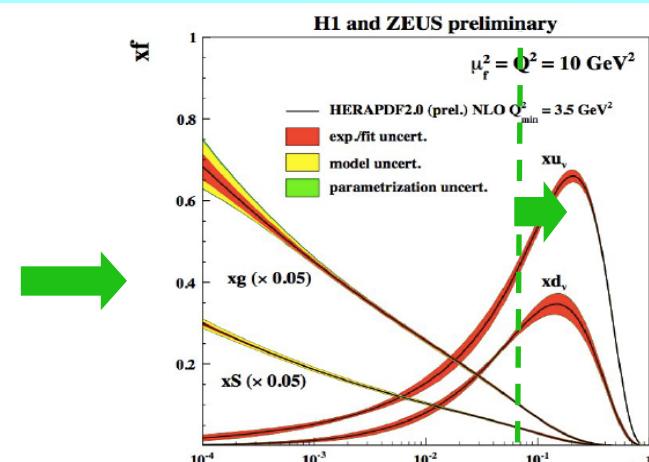


Lattice QCD



- $L^{u+d}$  (CI)
- $L^{u+d}$  (DI)
- $L^s$  (DI)
- $J^g$
- $\Delta \Sigma / 2 |^{u+d+s}$

Proton spin decomposition



X-dep distributions

**RBRC team: develop QCDOC**

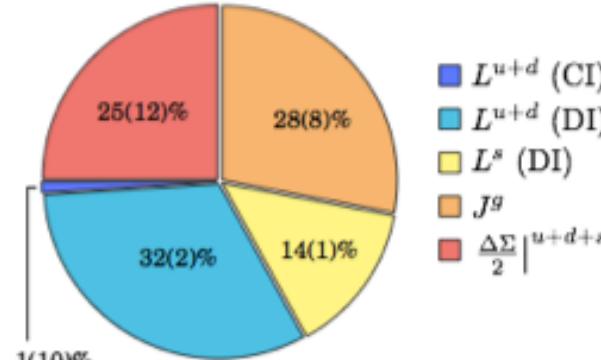
**Supercomputers**

# Lattice calculations of hadron structure

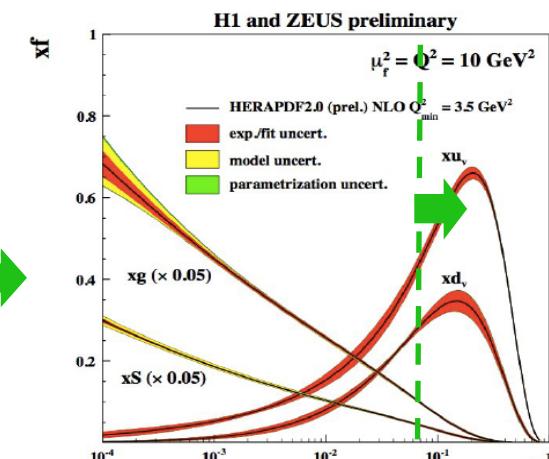


Lattice QCD

**RBRC team: develop QCDOC  
Supercomputers**



Proton spin decomposition



X-dep distributions

## ☐ New ideas – from quasi-PDFs (lattice calculable) to PDFs:

### ◊ High $P_z$ effective field theory approach:

$$\tilde{q}(x, \mu^2, P_z) = \int_x^1 \frac{dy}{y} Z\left(\frac{x}{y}, \frac{\mu}{P_z}\right) q(y, \mu^2) + \mathcal{O}\left(\frac{\Lambda^2}{P_z^2}, \frac{M^2}{P_z^2}\right)$$

### ◊ QCD collinear factorization approach:

$$\tilde{q}(x, \mu^2, P_z) = \sum_f \int_0^1 \frac{dy}{y} \mathcal{C}_f\left(\frac{x}{y}, \frac{\mu^2}{\bar{\mu}^2}, P_z\right) f(y, \bar{\mu}^2) + \mathcal{O}\left(\frac{1}{\mu^2}\right)$$

Parameter like  $\sqrt{s}$

Factorization scale

High twist Power corrections

Ji, et al.,  
arXiv:1305.1539  
1404.6680

Ma and Qiu,  
arXiv:1404.6860  
1412.2688  
Ishikawa, Qiu, Yoshida, .

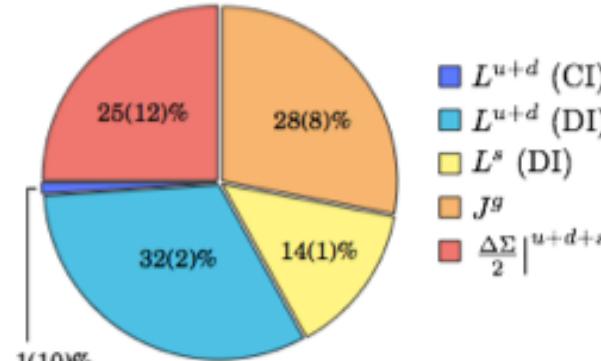
(RBRC)

# Lattice calculations of hadron structure

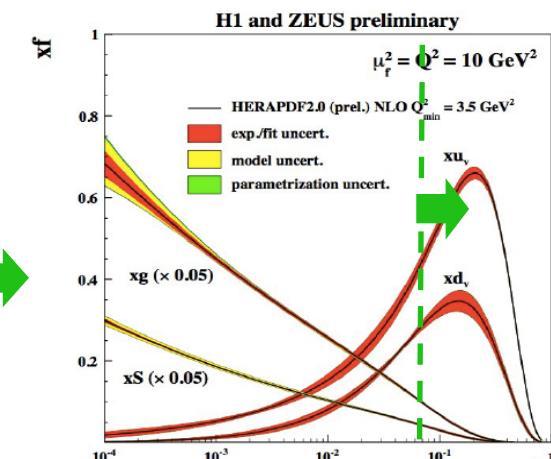


Lattice QCD

**RBRC team: develop QCDOC  
Supercomputers**



Proton spin decomposition



X-dep distributions

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(RBRC)

**Unmatched advantage:** PDFs of proton, neutron, pion, ..., and TMDs and GPDs, ...

# RBRC In-house Computing resources



2k node RBRC BGQ, 400 TFlops, 2012-  
1k node BNL BGQ, 200 TFlops, 2012-



3k nodes RBRC/BNL BGQ, 600 TFlops, 2012  
0.5 k nodes USQCD BGQ, 100 TFlops, 2013-  
2

- Rapid R&D of idea
- Try & error algorithms
- Optimize code on fully controlled **in-house machine**
- attract top-notch scientists
- define computing group



48 k node ALCF Mira, 10 PFlops



88 k node , AICS Kei, 11 PFlops

Extends / propagates to leadership computers  
Kei, ANL, ONL

many breakthroughs  
in science  
& computing



K ('12) @AICS ~ 10 Pflops peak

BG/Q('12) @Edinburgh ~ 1.2 Pflops peak



# RBRC Computing

RIKEN/Nishina  
and AICS

BNL theory  
HEP/NP/LGT

Japanese  
Institutions  
(KEK, Univ.  
Tsukuba)

**RIKEN-BNL**  
**Research**  
**Center**



QCDCQ('12) ~ 700Tflops peak

BNL comp  
CSC (HPC Code  
Center) / ITD

USQCD

US Universities  
(Columbia, ...)  
UKQCD  
(Edinburgh,....)



ANL Mira ('12) ~10 Pflops peak

# RBRC Heavy Ion Experiment

# Exp. Group activities

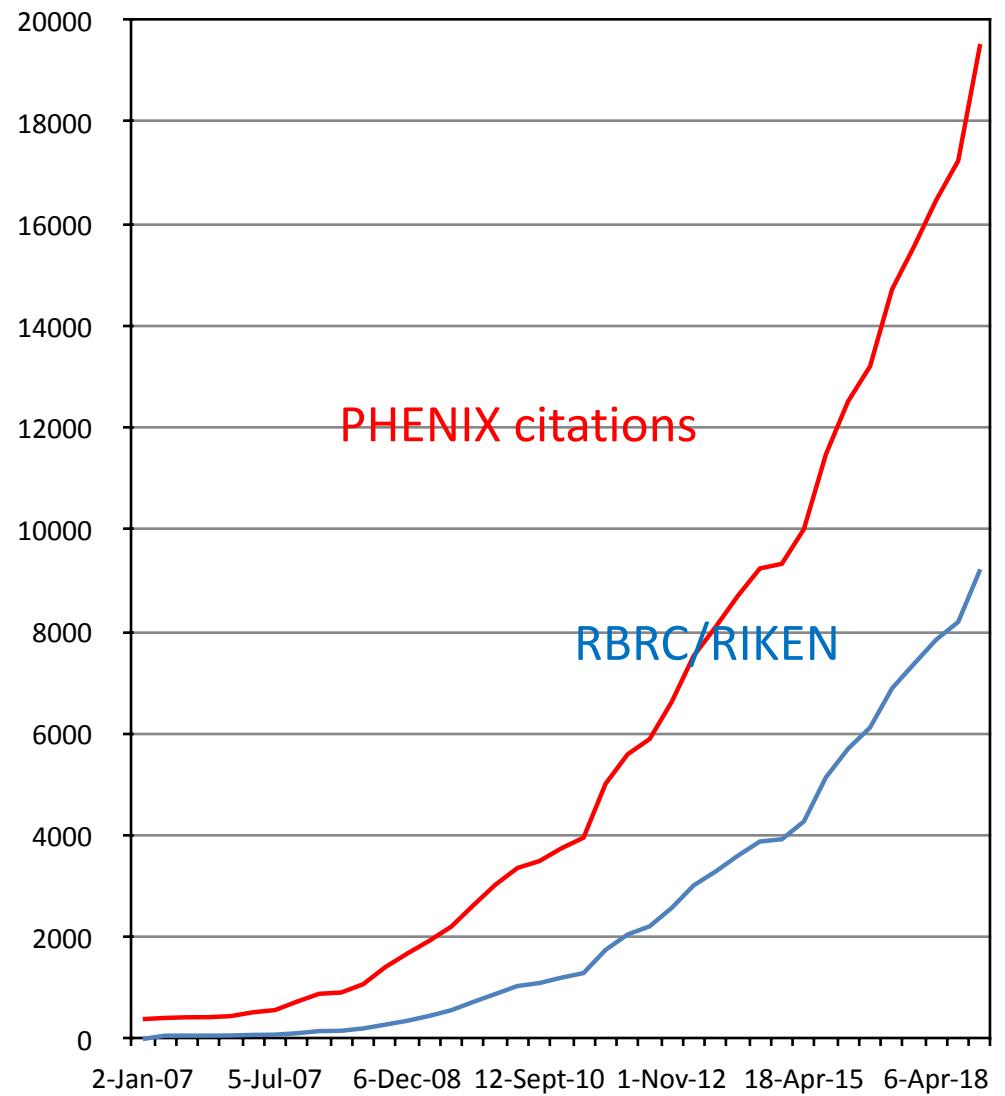
## Three major activities

- Spin Physics
  - Study of spin structure of proton using the world only polarized p+p collider
  - Main activity of RBRC/RIKEN
  - RBRC/RIKEN are the leader of Spin Physics at RHIC/PHENIX
- Heavy ion physics at RHIC/PHENIX
  - Study of the properties of the quark gluon plasma formed in heavy ion collisions at RHIC
  - RBRC/RIKEN are focused on penetrating probes
- PHENIX detector upgrades
  - Extend the capabilities of PHENIX for spin and heavy ion physics
  - $\mu$ Trig: (anti-quark spin via W) successful run in RUN13
  - VTX: (heavy quark probe of QGP) main detector for RUN14-16

# PHENIX publications and RBRC

- 148(60) papers published since 2001
  - Phys. Rev. Lett. 67 (27)
  - Phys. Rev. C 53 (19)
  - Phys. Rev. D 23 (12)
  - Phys. Letter B 4 (1)
  - Nucl. Phys. A 1 (1)
- Total citation: ~20000
  - Topcite 1000+ 1 (1)
  - Topcite 500+ 6 (3)
  - 250-500 15 (5)
  - 100-250 27 (18)
  - 50-100 28 (14)

The number in () is the number of papers with significant RIKEN/RBRC contributions (= member of paper writing committee)

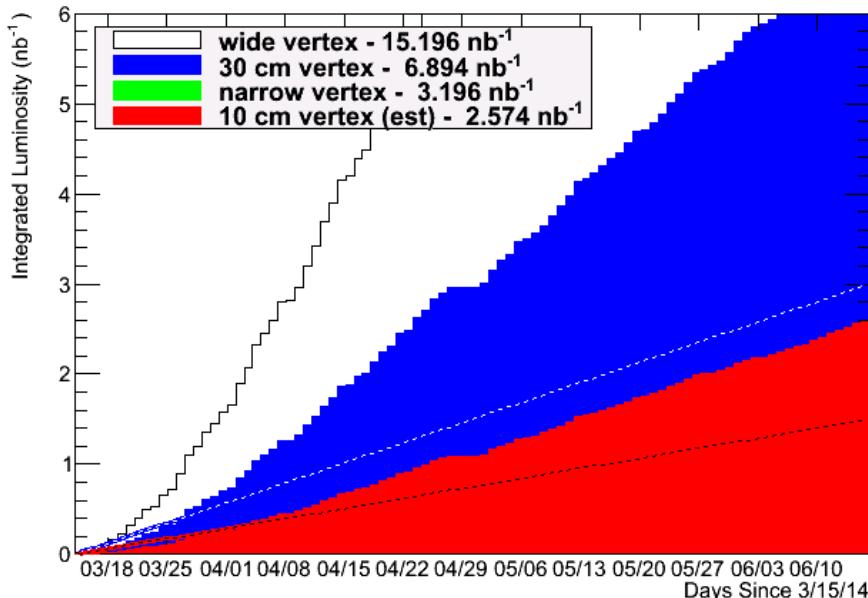


# RUN14: Au+Au 200 GeV “heavy quark” run

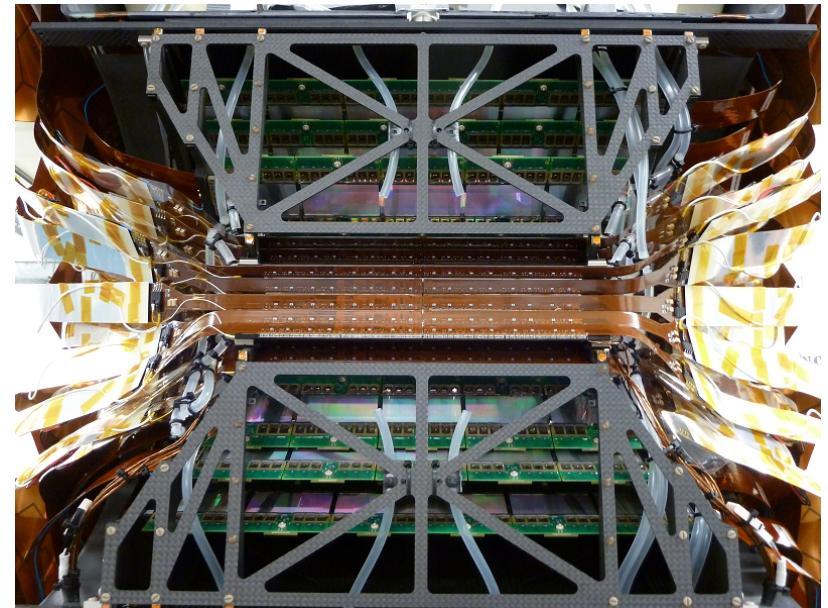
*Reaping harvest of VTX upgrade*

PHENIX Integr. Sampled Lumi vs Day

Mon Jun 16 09:01:47 2014



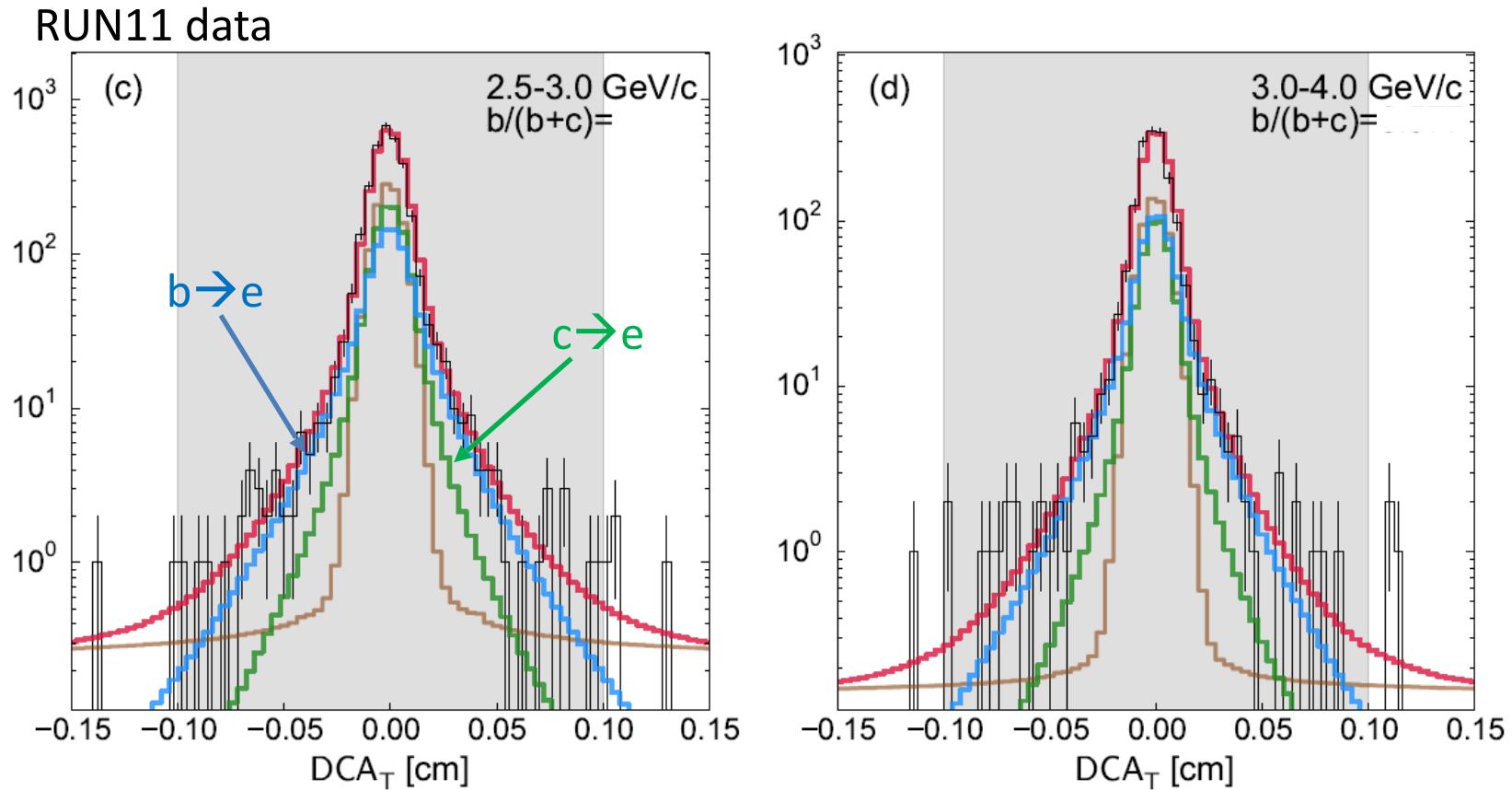
Integrated luminosity in RUN14



PHENIX VTX

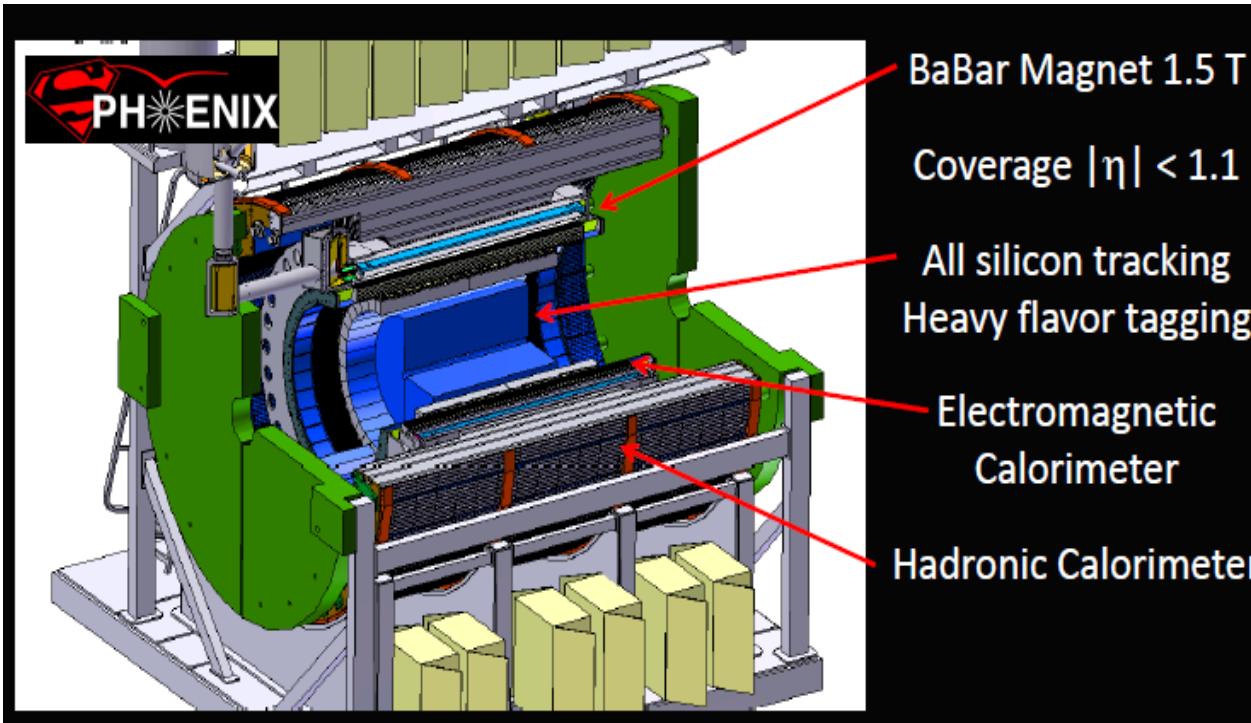
- 15 weeks of 200 GeV Au+Au
  - High statistics charm/quark measurement with VTX
  - VTX detector worked very well
  - PHENIX recorded ~20 billion events in VTX acceptance.
  - Data analysis of RUN14 data is on going. DST production of ¼ of the data has been complete

# Data analysis (VTX)



- The data analysis of Run11 VTX data is finalized
- Separate  $b \rightarrow e$  and  $c \rightarrow e$  from DCA measurements using an unfolding technique
- Obtained the charm and bottom hadron pT distributions and  $b/b+c$  ratios
- Draft of the paper has just released in PHENIX for internal review. Will be published before QM2015 in Kobe (9/27-10/3)
- RUN14 data analysis is in progress. Expect preliminary results in QM2015

# sPHENIX: jet detector for RHIC



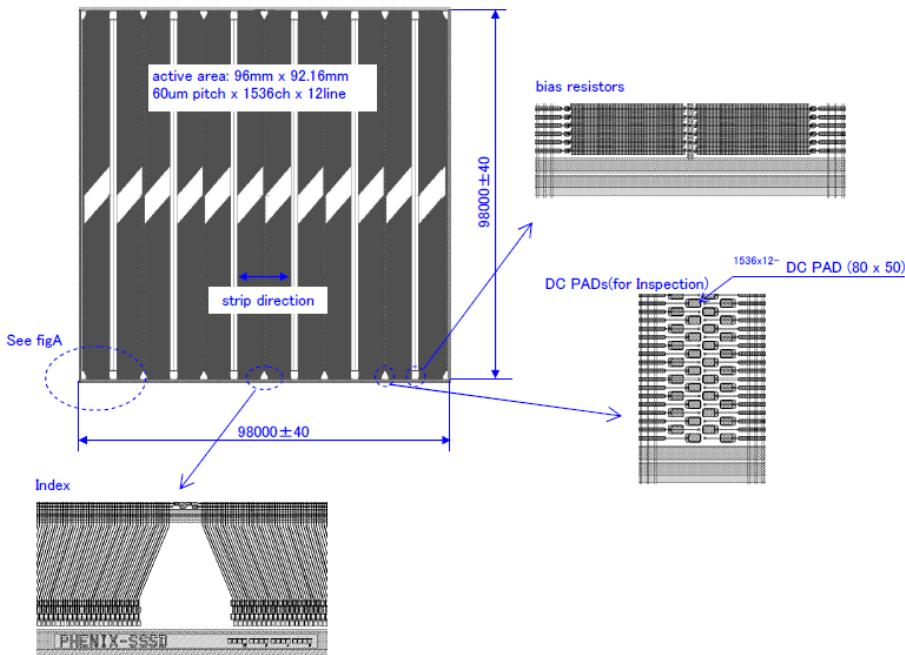
Babar solenoid



Arrived at BNL early this year

- Complete RHIC mission with Jets, photons, heavy quarks and Upsilon probes
- Passed DOE science review on April 30, 2015
- Commitment from BNL and strong endorsement from NSAC LPR
- An important opportunity for RBRC and RIKEN.
  - RBRC Exp-G and RIKEN is working on the silicon tracker of sPHENIX

# sPHENIX silicon tracker R&D



- Silicon sensor R&D at RIKEN in JFY2014
- Large Prototype sensor for the outer most layer
  - 96 mm x 92.16mm active area
  - 320  $\mu\text{m}$  thick
  - AC coupled
  - 6x128x24 mini-trips (60 $\mu\text{m}$  x 8mm)
  - 128x24 read-out channels
- 5 sensors manufactured at Hamamatsu and delivered to RIKEN in March 2015
- For all of 5 delivered sensors
  - No NG channels or strip
  - $V_{fd} = 50 \text{ V}$
  - $V_{breakdown} > 250\text{V} (>500\text{V} \text{ for two})$
- Second round of silicon module R&D has started.
- Produce working prototype silicon detector modules and test them in this JFY

I. Nakagawa, G. Mitsuka, YA

# RBRC Cosmology

# COSMOLOGY: UPDATE

- Yuki Okura joined the Cosmology effort at BNL about a year ago and has had an important impact on LSST and BNL's cosmology effort
- Working with members of the BNL Cosmology Group and the BNL Instrumentation Division Okura has measured very small manufacturing defects in the camera focal plane CCD sensors and determined their effect on LSST's ability to measure cosmic shear (important for dark energy constraints)
- He was able to show that the sensor defects were sufficiently small that they *do not* add significantly to the systematic error budget of the telescope
- Growth of this effort is under discussion

